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(54) ON-DEMAND HASH INDEX

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(22) Filed: **Aug. 13, 2013**

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G06F 17/30 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 17/3033*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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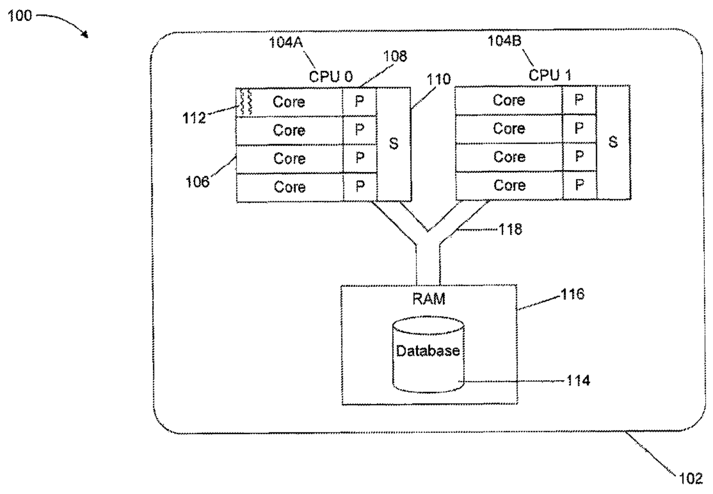
(57) **ABSTRACT**

Disclosed herein are system, method, and computer program product embodiments for populating a hash index and returning a handle to the hash index. An embodiment operates by determining, by at least one processor, during query optimization that a first database query has a query execution plan comprising a sub-query which executes N times a correlated predicate having an operator being one of equal and not equal to a base column. A cost of creating and probing the hash index N times and a cost of fully scanning the base column N times are compared based on the correlated predicate. Based on the comparing, it is determined whether to create on-demand a hash index.

20 Claims, 5 Drawing Sheets



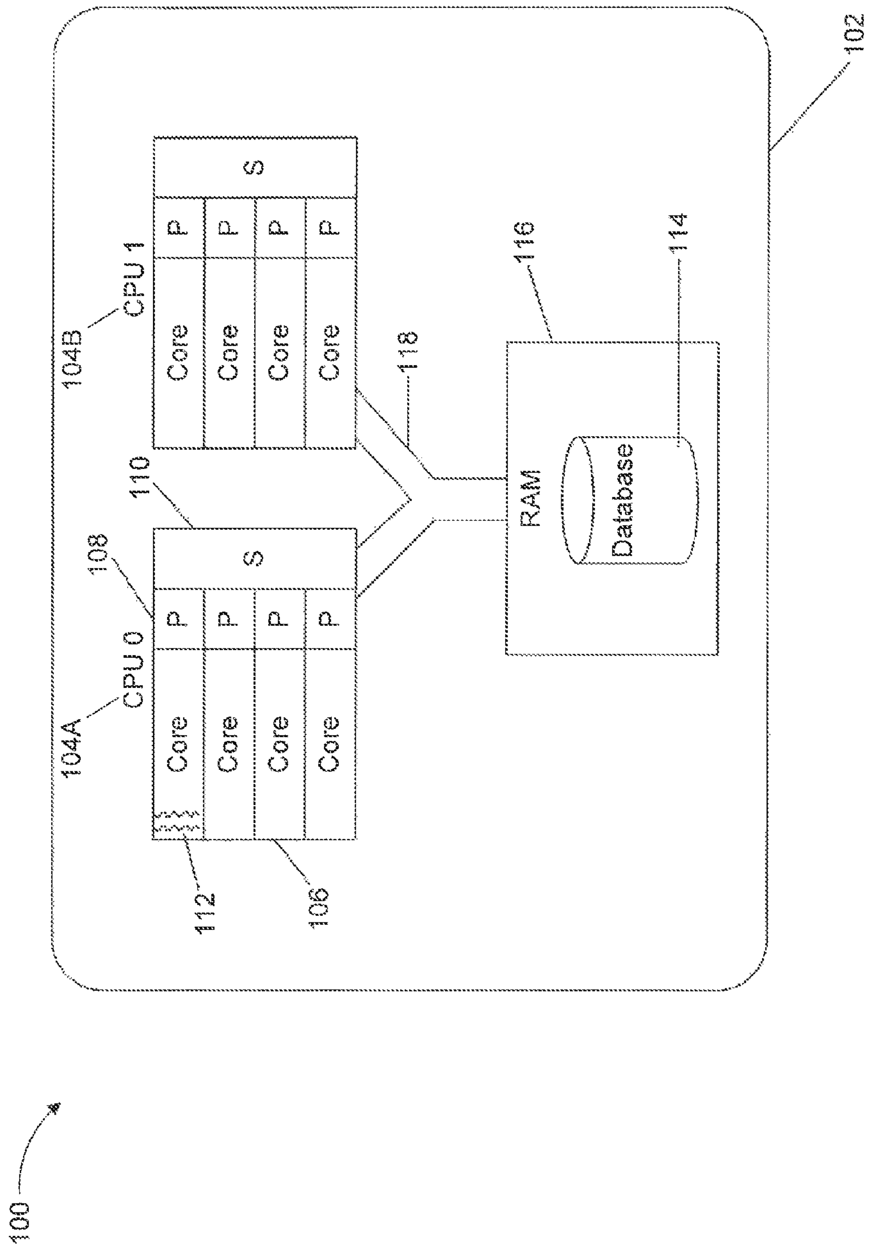

102
104B
CPU 1
S
P
P
P
P
Core
Core
Core
Core
118
116
114
110
108
104A
CPU 0
S
P
P
P
P
Core
Core
Core
Core
RAM
Database
112
106
100

FIG. 1

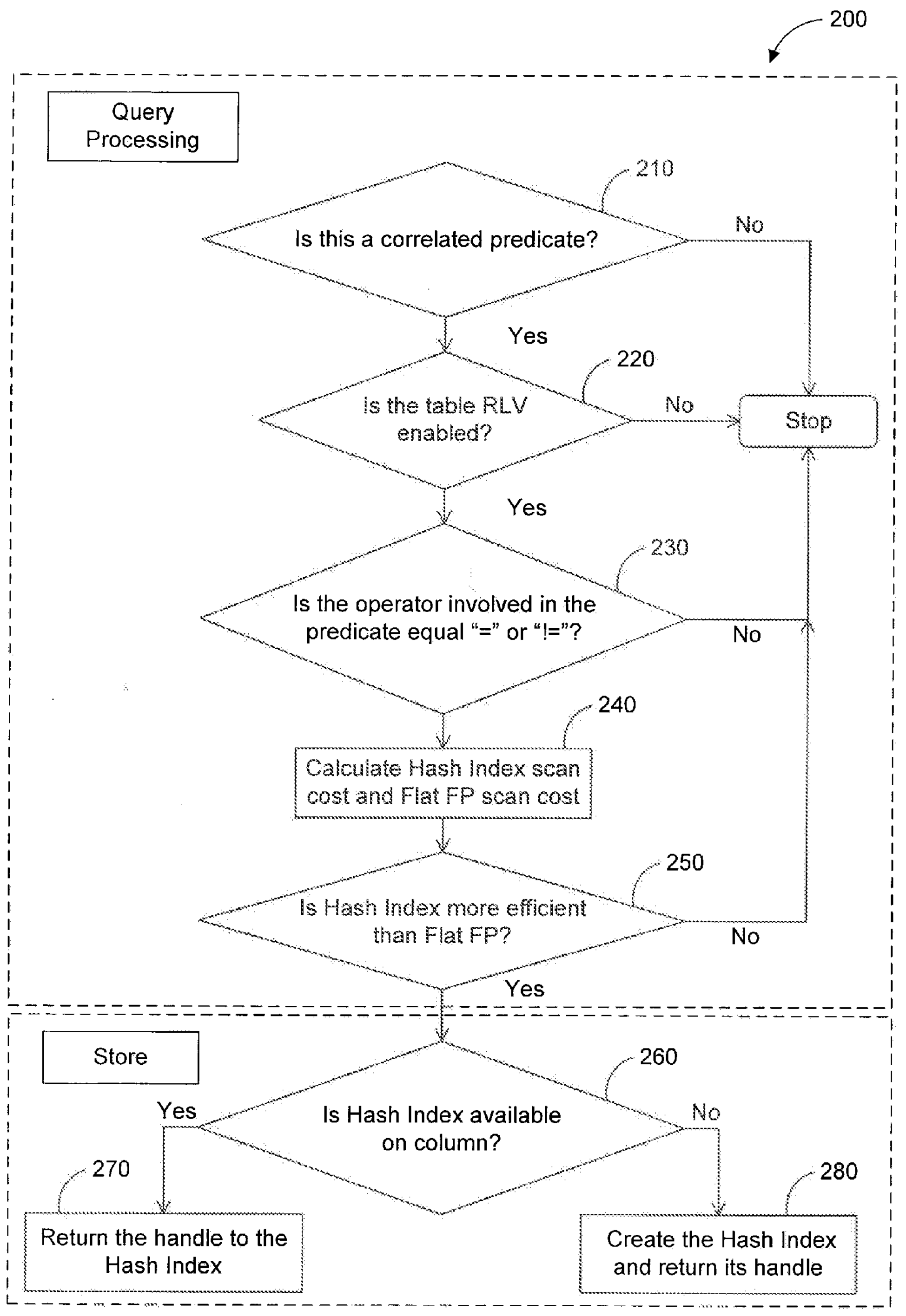

200
Query Processing
210
Is this a correlated predicate?
No
Yes
220
Is the table RLV enabled?
No
Stop
Yes
230
Is the operator involved in the predicate equal "=" or "!="?
No
240
Calculate Hash Index scan cost and Flat FP scan cost
250
Is Hash Index more efficient than Flat FP?
No
Yes
Store
260
Yes
Is Hash Index available on column?
No
270
Return the handle to the Hash Index
280
Create the Hash Index and return its handle

FIG. 2

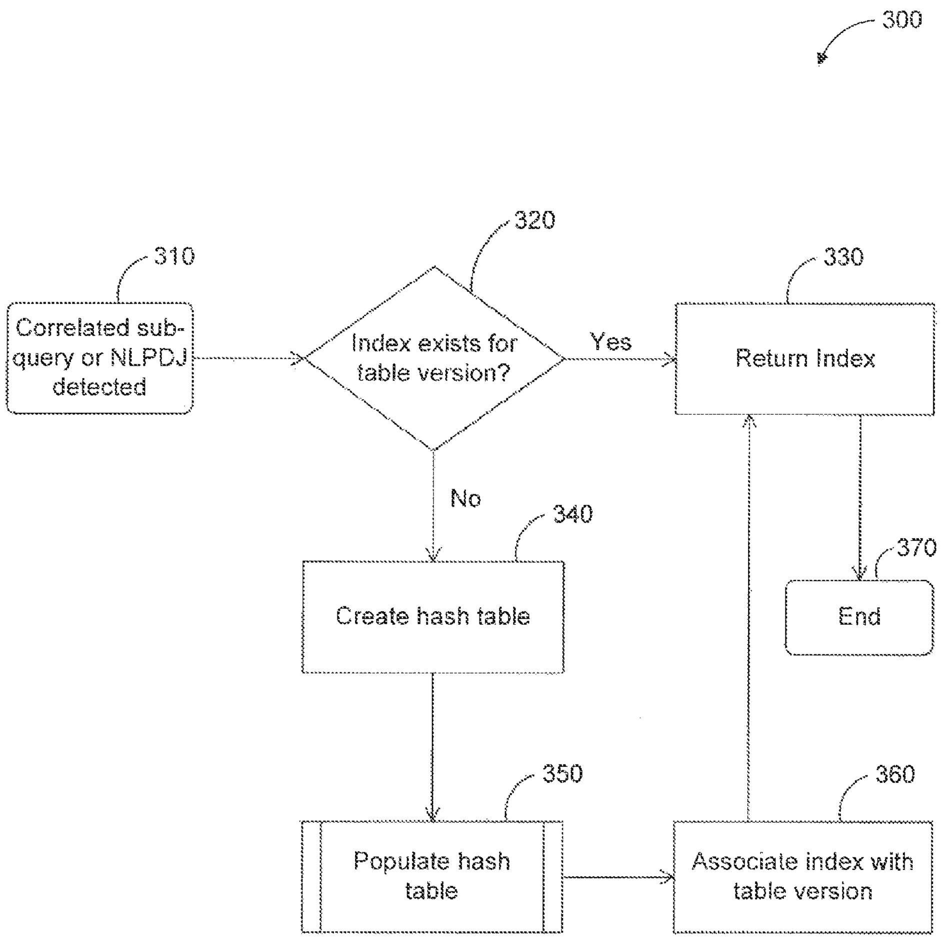

300
310
Correlated sub-query or NLPDJ detected
320
Index exists for table version?
Yes
330
Return Index
No
340
Create hash table
370
End
350
Populate hash table
360
Associate index with table version

FIG. 3

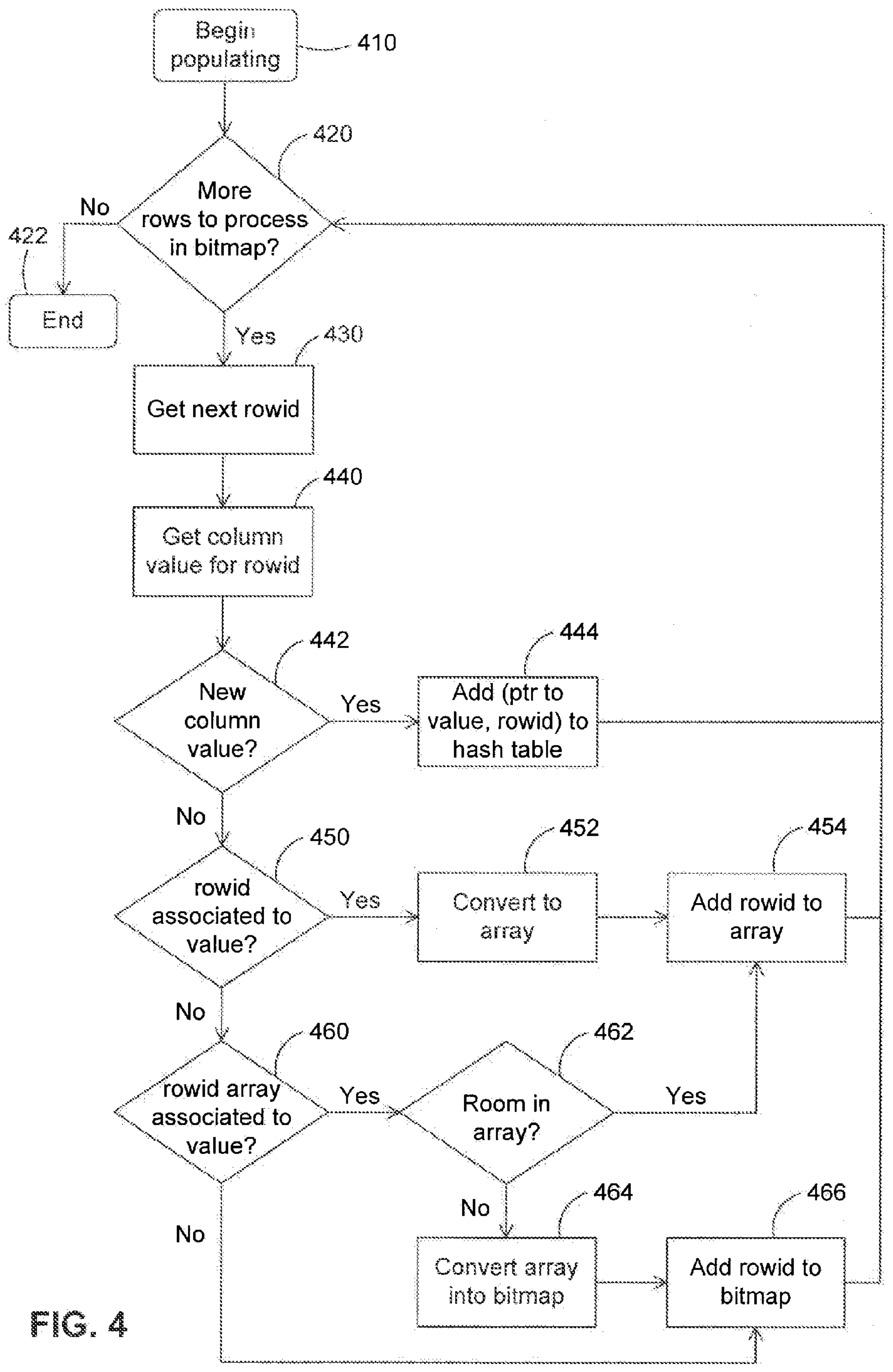

Begin populating
410
More rows to process in bitmap?
420
No
422
End
Yes
430
Get next rowid
440
Get column value for rowid
442
New column value?
Yes
444
Add (ptr to value, rowid) to hash table
No
450
rowid associated to value?
Yes
452
Convert to array
454
Add rowid to array
No
460
rowid array associated to value?
Yes
462
Room in array?
Yes
No
464
Convert array into bitmap
466
Add rowid to bitmap
No

FIG. 4

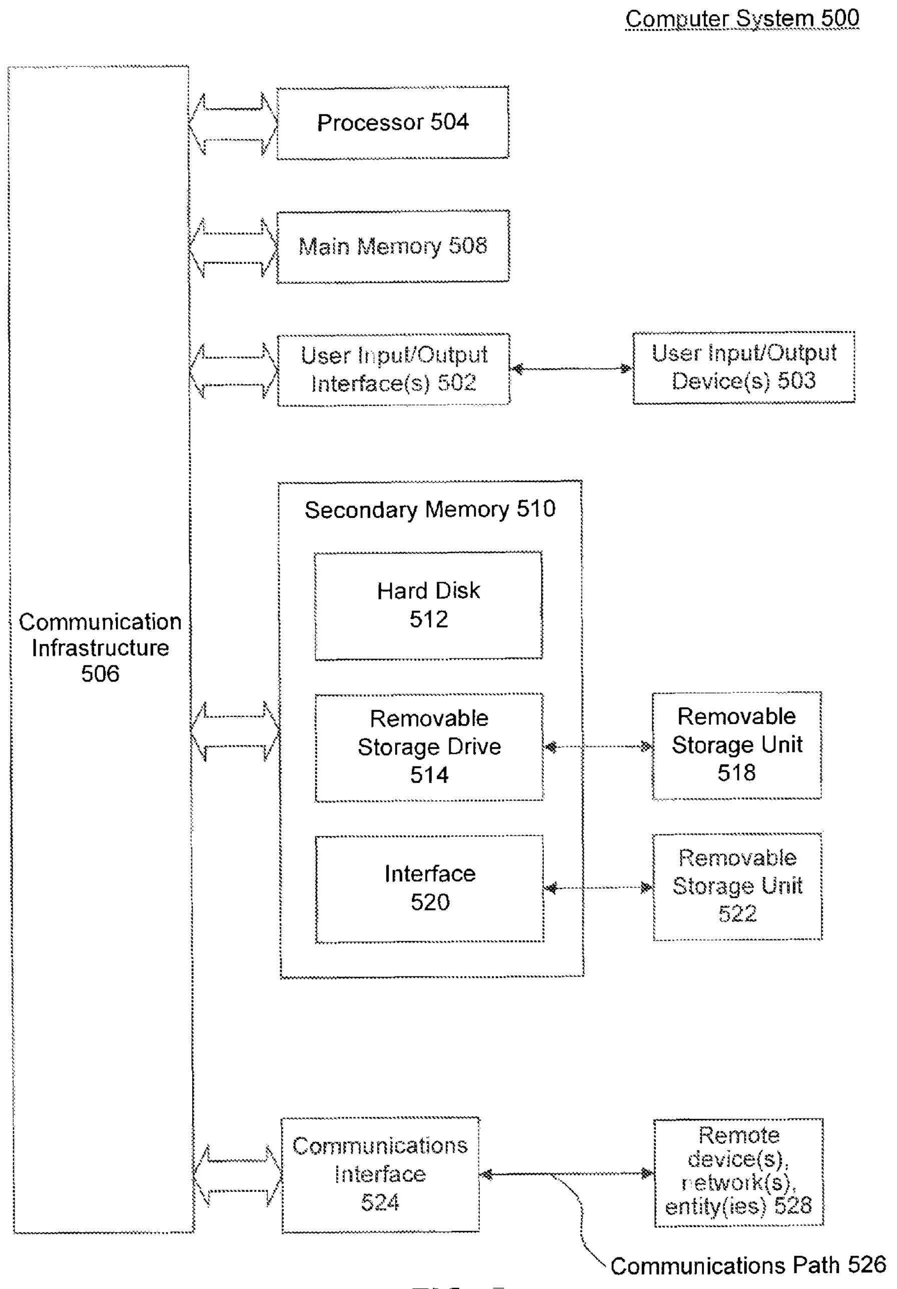

Computer System 500
Processor 504
Main Memory 508
User Input/Output Interface(s) 502
User Input/Output Device(s) 503
Secondary Memory 510
Hard Disk 512
Removable Storage Drive 514
Removable Storage Unit 518
Interface 520
Removable Storage Unit 522
Communication Infrastructure 506
Communications Interface 524
Remote device(s), network(s), entity(ies) 528
Communications Path 526

FIG. 5

ON-DEMAND HASH INDEX

BACKGROUND

Certain types of database queries include sub-queries where a column may be scanned a large number of times. In situations which involve these sub-queries, the associated database query may suffer from performance degradation. Conventional techniques for reducing a number of column scans include maintaining a plurality of secondary indexes. However, maintenance of these secondary indexes can result in a serious performance impact on write operations because each write operation may need to update all of the secondary indexes. Thus, these conventional techniques burden database writing and are not feasible for use with, for example, a column store database having a row level versioned (RLV) architecture.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are incorporated herein and form a part of the specification.

FIG. **1** is a block diagram of a database system, according to an example embodiment.

FIG. **2** is a flowchart illustrating checks before a hash index is created on-demand, according to an example embodiment.

FIG. **3** is a flowchart illustrating returning of a hash index, according to an example embodiment.

FIG. **4** is a flowchart illustrating populating a hash table, according to an example embodiment.

FIG. **5** is an example computer system useful for implementing various embodiments.

In the drawings, like reference numbers generally indicate identical or similar elements. Additionally, generally, the left-most digit(s) of a reference number identifies the drawing in which the reference number first appears.

DETAILED DESCRIPTION

Provided herein are system, method and/or computer program product embodiments, and/or combinations and sub-combinations thereof, for populating a hash index and returning a handle to the hash index.

Example Block Diagram of Database Architecture

FIG. **1** shows a block diagram of a database system **100** according to an example embodiment. The database system **100** may be, but is not limited to, an in-memory database system. As shown in FIG. **1**, database system **100** may include a computer **102** having at least one processor **104**. As an example, the database system **100** in FIG. **1** is shown having two processors, but the database system is not limited to having two processors and may have a single processor or more than two processors. Each processor **104** may include a plurality of cores **106** each having a private cache **108**. As an example, CPU **0** **104**A and CPU **1** **104**B in FIG. **1** are shown as having four cores **106** each, but the processors may include less than four cores or more than four cores. Each processor **104** may include caches **108** and cache **110** that is shared among its cores. Each core **106** may have a plurality of hardware contexts, e.g. threads **112**. In addition, the computer **102** includes random-access memory (RAM) **110** which may include hundreds of GB or TBs of RAM. According to example embodiments, the database system **114** may be an in-memory column-store database system stored and executed within RAM **116**. Thus, in an embodiment, as opposed to conventional database systems stored on disk where disk access and speed presents a bottleneck, the RAM

116 of an in-memory database system may present a bottleneck for the faster caches **108** and **110**. The RAM **116** having the database system **114** and processors **104** may communicate via a bus **118**.

According to an example embodiment, the database system **114** includes an in-memory intermediate store that is introduced in order to make write operations faster. An RLV enabled database table may include a fast projection index (flat FP index) on each of its columns. This flat FP index is a default index which is created when a table is created. All column values are stored in this default index. This default index is associated with each row in the table which enables certain kinds of search conditions to be evaluated. Each column may have one FP index, and each FP may be an array of n fixed-length entries being column values where n is the number of rows in the table. Each column value may then be stored sequentially in order. In order to keep write operations efficient, secondary indexes such as a hash index/btree index are typically not maintained or supported in an RLV store. Updating a secondary index during write operations would degrade write performance/efficiency of the store.

Processing Queries which Degrade Performance

Certain types of database queries may include sub-queries which involve scanning a column in a database an excessive number of times. According to example embodiments, if one of these database queries is detected, a hash index may be created for use with the instant query and then reused for subsequent queries, if applicable. The hash index is to be created by a reader of the database such that readers, not writers, pay the price of creating the index. This is beneficial in an RLV enabled table as index maintenance costs are offloaded to the readers, rather than burdening writers to the database. These costs may therefore be amortized over a plurality of readers of a same version of a database table. Detection of these database queries which may degrade performance may occur early in the optimization phase.

For example, a column may be scanned a large number of times if a database query includes correlated sub-queries. As a non-limiting example, a database query may be the following:

```
select*from outer where outer.c1 in(select inner.c1
    from inner where inner.c1=outer.c1)
```

In this example, inner.c**1** will be scanned for every value of outer.c**1**. While it is possible to only consider distinct values of outer.c**1**, if c**1** is the primary key, there still may be a very high number of distinct values. If outer.c**1** includes a million distinct values, then the inner query block will be executed a million times. For the above query, inner.c**1**=outer.c**1** is a correlated predicate, where outer.c**1** is an outer column, inner.c**1** is an inner column, and "=" is an operator.

A query engine may conduct optimization on data. According to an embodiment, the query engine may sort data on outer.c**1** such that all duplicates for a given unique value may sit next to each other in sorted data. Thus, for outer unique values, an inner query may be executed while outer duplicate values may use results generated by the unique value.

As an example, we may assume that outer.c**1** includes the following values: b, a, c, a, c, c. After these values are sorted, they will be: a, a, b, c, c, c. An inner query may be executed for the first a, and a second a will use the result generated b the first a. Similarly, for an inner query for the first c, the second and third c may use the result generated by the first c. Thus, an inner query may only be executed for unique outer values. The inner query will only be executed three times for a, b, and c outer values.

As a further non-limiting example, the query may include a nested loop push down join query (NLPDJ):

```
select rvt.c1 from rvt1, rvt2 where rvt1.c1=rvt2.c1
```

In this example, the NLPDJ will likely cause an exorbitant number of column scans which take significant time and degrade performance. For the above query, rvt**1**.c**1** is an inner column, and rvt**2**.c**1** is an outer column.

According to an example embodiment, performance degradation may be alleviated by creating and utilizing a hash index on-demand. If the database system **114** detects one of the above example sub-query scans, the database system **114** may initiate creation of a hash index on a column in the database. This index may be made private to the database system **114** and will be unknown to a user accessing or writing to the database. The database system **114** will have ownership over creation and destruction of the index.

As a result, if the database system **114** detects a performance impairing query such as one of the examples provided above, and the database table is RLV enabled, the database system **114** may initiate creation of the index as described further in detail below.

Query scenarios including NLPDJ and correlated sub-queries may result in creation of the hash index when an operator in the correlated predicate is either equal or not-equal. After the index is created, it may be used for predicate evaluation. Once the query is completed, the index may be closed, however, once it is created the index may be used for multiple queries.

If a hash index is already created on a column by a correlated sub-query, this hash index can be utilized by any query using/working on the same version of the table.

According to an example embodiment, query Q**1** creates a hash index on inner.c select*from outer where outer.c**1** in(select inner.c**1** from inner where inner.c**1**=outer.c**1**). For query Q**2**, the hash index created by Q**1** can be reused even though it is not a correlated sub-query. As an example, query Q**2** may be: select*from inner where inner.c=10.

However, there are instances where it may not be cost effective to create a hash index. According to an example embodiment, a cost model may compare the execution cost of the database query using the flat FP index with the cost of using the hash index. This cost model is described below. There may be situations where the cost of the creation of the hash index combined with the cost of probing the hash index may outweigh the column scans associated with use of the flat FP index. For example, the cost of using the hash index may be too high when there are very few rows in the inner and outer tables. In order to avoid creation of the index in such cases where the cost is too high, a cost model is used in order to determine whether the creation of the index may be beneficial.

Cost Model

In an embodiment, the cost model is based upon a number of equations and pseudocode, non-limiting examples of which are provided below.

Terms and Constants

innerRVTableCard=Cardinality of the inner table

innerRVColDistCard=Distinct count of the inner column

outerTableCard=Cardinality of the outer table

outerColDistCard=Distinct count of the outer column

CPU_factor=1.1;

Additional_Overhead=0;

Memory_Factor=1;

Hash_Insert_Factor=1.01;

// Note that the above values are based on experiments to verify functionality of the Cost Model

```
Equations & Pseudocode for Cost Model
// Compute the cost of using the Flat FP index
// Begin equations & pseudocode
costWithFlatFP = outerColDistCard * (innerRVTableCard *
(CPU_Factor * Cell_Size));
// Compute the cost of creating and probing the Hash Index
Memory_Allocated_For_Keys = 8 * innerRVTableDistCard;
if (TableCard / ColDistCard == 1) {
    Memory_Allocated_For_Values =innerRVColDistCard *
(40 bytes + 8);
    // rowid found
}
else if (TableCard / ColDistCard < 128) {
    Memory_Allocated_For_Values = innerRVColDistCard *
(40 bytes + 8 * 128);
    // array of rowids
}
else {
    Memory_Allocated_For_
Values = innerRVColDistCard * (40 bytes +
    (TableCard/ColDistCard/NumBitsPerChunk) *
(52 + NumBitsPerChunk/8));
    // bitmap of rowids
}
Approximate_Memory_Allocated = Memory_
Allocated_For_Keys +
Memory_Allocated_For_Values + Additional_Overhead;
Memory_Cost = Approximate_Memory_Allocated *
Memory_Factor;
Column_Scan_Cost_Of_The_Inner_
Table = innerRVTableCard *
CPU_Factor * Cell_Size;
Hash_Creation_Cost = (Column_Scan_Cost_Of_The_Inner_Table *
Hash_Insert_Factor) + Memory_Cost;
Hash_Probe_Cost = outerTableDistCard * CPU_Factor;
// The hash probe cost is the cost of computing the hash value for each
distinct outer value
// + cost of walking array of size 4 + the cost of one comparison
costWithHashIndex = Hash_Creation_Cost + Hash_Probe_Cost;
// End equations & pseudocode
```

When determining how much memory to allocate, values may be accepted in order to estimate how many unique data values in the column are expected. These estimates may assist in avoiding underallocating or overallocating memory and avoiding allocation cost. However, if the estimates are not accurate, the database system is able to dynamically reallocate memory.

In view of the above equations and pseudocode, the cost model may be used in order to determine whether to create the hash index. Therefore, the hash index may be created only if costWithHashIndex<costWithFlatFP. However, as further described below; the Hash_Creation_Cost will be 0 as long as the hash index has already been created.

Hash Index Creation

According to an embodiment, FIG. **2** shows a flowchart **200** illustrating a process of hash index creation. In step **210**, during query optimization when a query is determined to be a query that overscans and causes performance degradation, for every outer reference in the query block, it is determined whether a correlated predicate is found to be present. If a correlated predicate is not present, then the process stops because a hash index is not needed and is not created.

In step **220**, if a correlated predicate is found, then it is determined whether the table is RLV enabled. If the table is not RLV enabled, then the process stops because a hash index is not needed and is not created.

In step **230**, if the table is RLV enabled, then it is determined whether the operator involved in the correlated predicate is equal ("=") or not equal ("!="). If the operator involved in the correlated predicate is not one of these operators, then a hash index is not needed and is not created.

In step **240**, if the operator is equal or not equal, the cost of creating a hash index and the cost of a flat FP scan is computed as described above. If the cost of the hash index is determined to be less than the cost of the flat FP scan, then a hash index is not needed and is not created.

In step **250**, if creating/probing the hash index is determined to be an efficient use of resources and less than the cost of a flat FP scan, then it is determined whether a hash index has already been created.

In step **260**, if the hash index has already been created, a handle to the hash index is returned in step **270** and the process ends.

In step **260**, if the hash index has not yet been created, then in step **280** the hash index is created and a handle to the hash index is returned.

If the index is being created and populated by another query, query processing waits for the index to be populated and both (or more) waiting queries may re-use the index. Hence, at most one hash index is created for each specific version of the table. A first query that finds the query index beneficial creates the index, and other concurrent queries get blocked and wait until the first query completes the creation and population of the index.

According to an example embodiment, and as shown in FIG. **2**, during query processing and depending upon the type of query being processed, if evaluation of the hash index cost model for the column is determined to be lower than the cost of scanning using the flat FP index; then the hash index is created and populated if it does not yet exist. A handle is then returned to the hash index. If the hash index is determined to be more cost effective and has already been populated, then a handle to the hash index is returned.

Index Creation and Maintenance

Each hash index may include a hash table that is created according to the process described herein. This hash table associates column values with rows. As an example, given a set of rows associated with a particular version of the table, the hash index for a column of the table may include as many entries as different values are in the column that are being indexed for the set of rows. Each value in the hash table may be associated with a row position(s) in the table and a particular value in the column. The column store is implemented as an append-only column store, e.g., no data is deleted from the store. Thus, instead of copying each different value into the hash table, a pointer is associated with a first occurrence of a value in the column as determined by the rows in the table version.

In other words, each element of the hash table includes a pointer to a data value, and a row specification. The row specification is described further herein, but may be a rowid, an array of rowids, or a bitmap of rowids. In other words, the row specification may be a rowid (e.g. a position of the row in the table) if only one row has the value, an array of rowids if a plurality of the rows have the value (e.g. 100 rows have the same value such as “M” or “F” and the array has a capacity of 128), or a bitmap if more rows than can fit in the array have the value of “M” or “F.” The capacity of the array provided here is merely an example, and may he a value that is higher or lower than 128.

Lifetime of the Index

Each hash index is associated to a table version that is assigned to the transaction that triggered hash index creation. In other words, a particular hash index is only available to transactions which use a same table version which the hash index is associated with.

Populating a Hash Index

According to an embodiment, FIGS. **3** and **4** show flowcharts illustrating a process of returning and populating a hash index if its use is determined to be cost effective. First, a

column that is being indexed is scanned by walking the values in the column. Rows in the column associated with the table version are retrieved during the scan by utilizing an existence bitmap that is associated with the table version. The existence bitmap of the table version is used to identify a sequence of rowids that are enumerated by position in the table. The enumerated rows that are included in the existence bitmap are rows in the table which are included in this particular table version.

Therefore, using the existence bitmap, based on the column value for each row in the table version, the hash index is populated. When a new column value is identified during the scan of the column, a pointer to the value is added to the hash table along with the rowid of the row that contains the value. Later during the scan, if another row is determined to have the same value, then an array of rowids is associated to the value in the hash table. If the array becomes full during the scan of the column, then a bitmap may be created to refer to all rowids associated with a particular value. The rowids which are in the array are inserted into the bitmap, the bitmap is associated to the column value in the hash table, and the array is discarded (deallocated).

Once all database transactions using the table version are complete, and a more recent version of the table exists, the hash index is discarded (deallocated) along with the table version.

FIG. **3** shows a process **300** of returning a hash index according to an example embodiment. In step **310**, the process begins when a database query having a correlated subquery or an NLPDJ is detected by the query optimizer.

In step **320**, it is determined whether an index already exists for a particular table version.

In step **330**, if the index already exists for the table version, then the index is returned and the process of populating the hash index ends in step **370**.

In step **340**, if the index does not yet exist, a hash table is created. In step **350**, after the hash table is created it is populated, which is described in detail below.

In step **360**, the index is associated with the particular table version and the index is returned in step **330**.

In step **370**, the process of returning the hash index ends.

FIG. **4** shows a process of populating the hash table in detail according to an example embodiment. Thus, FIG. **4** includes the details of populating the hash table in step **350** shown in FIG. **3** and may be viewed as a loop.

In step **410**, the process of populating the hash table in step **350** begins.

In step **420**, the process enters a loop that is executed while there are additional rows to process in the existence bitmap for the table version.

In particular, in step **420**, if it is determined that there are additional rows to process, then the process moves onto step **430** where the value associated with the next rowid is retrieved.

However, if there are no additional rows to process in the bitmap, then the process of populating the hash table ends in step **422**.

After the next rowid is determined using the existence bitmap in step **430**, the column value is retrieved for the rowid in step **440**.

If this column value is determined to be a new value in step **442**, then in step **444** a new pair is added to the hash table including a pointer to the column value and the associated row id.

However, if the column value is not a new value, then it is determined whether another rowid is already associated with the value in step **450**. If another rowid is already associated with the value, then in step **452**, the rowid in the hash table is converted into an array and the rowid is inserted into the array. The second rowid is inserted into the array in step **454**.

If the column value is not a new value (step **442**) and it is determined that a rowid array is already associated with the value (step **450**), then it is determined whether there is an associated array in step **460**. If there is an associated array, then in step **462**, it is determined whether there is room in the array. If it is determined that there is additional room in the array, then the rowid is added to the array in step **454**. However, if the array is full, then in step **464** the array is converted into a bitmap and all rowids in the array are added to the bitmap. The new rowid is added to the bitmap in step **466**.

If the column value is not a new value and it is determined that a rowid array is not associated with the value, then it is determined whether there is an associated bitmap in step **460**. If there is an associated bitmap, then the rowid is added to the bitmap in step **466**.

According to an example embodiment, the hash index is an insert only index. Thus, since nothing can be deleted, a bitmap cannot be reduced to an array, and an array cannot be reduced to a single rowid. The hash table may be populated using pointers to a value associated with rowids by using a variety of data structures. Each entry into the hash table may include (1) a pointer to a value/rowid, (2) a pointer to a value/array of rowids or (3) a pointer to a value/bitmap of rowids to address diversity in the data in the table. Thus, the hash table is able to represent data found throughout a high percentage of the rows, some of the rows, or even only one of the rows.

Analysis of On-Demand Hash Index

The on-demand hash index was analyzed by conducting experiments in order to test the veracity of the cost model and gain in performance using the hash index. Experiments were conducted using database system **114** as described above.

According to an example embodiment, tables in the database system were RLV enabled having one column (c**1**) with all data stored in main memory (RLV only data). A distinct count of the inner column was hard coded to be 100. Each experiment described herein was conducted ten times and an average value in milliseconds was computed for each.

Parameter Values

CPU_Factor=1.1

Additional_Overhead=0

Memory_Factor=1

Hash_Insert_Factor=1.01

Sample Queries

Experiment1: select*from R**100**D**100** where R**100**D**100**.c**1** in(select R**1**KD**100**.c**1** from R**1**KD**100** where R**1**KD**100**.c**1**=R**100**D**100**.c**1**)–Gain 0.57%, No Hash Index

Experiment2: select*from R**1**KD**100** where R**1**KD**100**.c**1** in(select R**100**D**100**.c**1** from R**100**D**100** where R**1**KD**100**.c**1**=R**100**D**100**.c**1**)–Gain 15.38%, Hash Index created

Experiment3: select*from R**100**D**100** where R**100**D**100**.c**1** in(select R**10**KD**100**.c**1** from R**10**KD**100** where R**10**KD**100**.c**1**=R**100**D**100**.c**1**)–Gain 32.69%, Hash Index created

Experiment4: select*from R**10**KD**100** where R**10**KD**100**.c**1** in(select R**100**D**100**.c**1** from R**100**D**100** where R**10**KD**100**.c**1**=R**100**D**100**.c**1**)–Gain 11%, Hash Index created

Experiment5: select*from R**100**D**100** where R**100**D**100**.c**1** in(select R**1**MD**100**.c**1** from R**1**MD**100** where R**1**MD**100**.c**1**=R**100**D**100**.c**1**)–Gain 53.62%, Hash Index created

Experiment6: select*from R**5**D**5** where R**5**D**5**.c**1** in(select R**1**MD**100**.c**1** from R**1**MD**100** where R**1**MD**100**.c**1**=R**5**D**5**.c**1**)–Gain 21.55%, Hash Index created

Experiment7: select*from R**5**D**5** where R**5**D**5**.c**1** in(select R**100**D**100**.c**1** from R**100**D**100** where R**5**D**5**.c**1**=R**100**D**100**.c**1**)–Gain −5.11%, No Hash Index

Results

Experiment #	#RowsOuterTable * #RowsInnerTable	Execution Time with Flat FP Index (msec)	Execution Time with Hash Index (msec)	% Gain	Hash Index Created (Based on Cost Model Decision)
1	100 * 1000	245.3	243.9	0.57	No
2	1000 * 100	1554.5	1315.3	15.38	Yes
3	100 * 10000	363.1	244.4	32.69	Yes
4	10000 * 100	14561.3	12853.9	11	Yes
5	100 * 1000000	10228.3	4743.8	53.62	Yes
6	5 * 1000000	765.1	592.5	22.55	Yes
7	5 * 100	70.3	74.6	−6.11	No

According to the above described experiments based on the example embodiments, for tables having a fewer number of rows, memory overhead for creation of the hash index will overshadow any performance benefits (e.g. as seen in Experiments 1 and 7). However, as the number of rows increase, the performance gain resulting from use of the hash index increases. In conclusion, the cost model favors use of the hash index if it is more efficient than the that FP index when taking all costs into consideration.

Example Computer System

Various embodiments can be implemented, for example, using one or more web-known computer systems, such as computer system **500** shown in FIG. **5**. Computer system **500** can be any well-known computer capable of performing the functions described herein, such as computers available from International Business Machines, Apple, Sun, HP, Dell, Sony, Toshiba, etc.

Computer system **500** includes one or more processors (also called central processing units, or CPUs), such as a processor **504**. Processor **504** is connected to a communication infrastructure or bus **506**.

One or more processors **504** may each be a graphics processing unit (GPU). In an embodiment, a GPU is a processor that is a specialized electronic circuit designed to rapidly process mathematically intensive applications on electronic devices. The GPU may have a highly parallel structure that is efficient for parallel processing of large blocks of data, such as mathematically intensive data common to computer graphics applications, images and videos.

Computer system **500** also includes user input/output device(s) **503**, such as monitors, keyboards, pointing devices, etc., which communicate with communication infrastructure **506** through user input/output interface(s) **502**.

Computer system **500** also includes a main or primary memory **508**, such as random access memory (RAM). Main memory **508** may include one or more levels of cache. Main memory **508** has stored therein control logic (i.e., computer software) and/or data.

Computer system **500** may also include one or more secondary storage devices or memory **510**. Secondary memory **510** may include, for example, a hard disk drive **512** and/or a removable storage device or drive **514**. Removable storage drive **514** may be a floppy disk drive, a magnetic tape drive, a compact disk drive, an optical storage device, tape backup device, and/or any other storage device/drive.

Removable storage drive **514** may interact with a removable storage unit **518**. Removable storage unit **518** includes a computer usable or readable storage device having stored thereon computer software (control logic) and/or data. Removable storage unit **518** may be a floppy disk, magnetic tape, compact disk, DVD, optical storage disk, and/any other computer data storage device. Removable storage drive **514** reads from and/or writes to removable storage unit **518** in a well-known manner.

According to an exemplary embodiment, secondary memory **510** may include other means, instrumentalities or other approaches for allowing computer programs and/or other instructions and/or data to be accessed by computer system **500**. Such means, instrumentalities or other approaches may include, for example, a removable storage unit **522** and an interface **520**. Examples of the removable storage unit **522** and the interface **520** may include a program cartridge and cartridge interface (such as that found in video game devices), a removable memory chip (such as an EPROM or PROM) and associated socket, a memory stick and USB port, a memory card and associated memory card slot, and/or any other removable storage unit and associated interface.

Computer system **500** may further include a communication or network interface **524**. Communication interface **524** enables computer system **500** to communicate and interact with any combination of remote devices, remote networks, remote entities, etc. (individually and collectively referenced by reference number **528**). For example, communication interface **524** may allow computer system **500** to communicate with remote devices **528** over communications path **526**, which may be wired and/or wireless, and which may include any combination of LANs, WANs, the Internet, etc. Control logic and/or data may be transmitted to and from computer system **500** via communication path **526**.

In an embodiment, a tangible apparatus or article of manufacture comprising a tangible computer useable or readable medium having control logic (software) stored thereon is also referred to herein as a computer program product or program storage device. This includes, but is not limited to, computer system **500**, main memory **508**, secondary memory **510**, and removable storage units **518** and **522**, as well as tangible articles of manufacture embodying any combination of the foregoing. Such control logic, when executed by one or more data processing devices (such as computer system **500**), causes such data processing devices to operate as described herein.

Based on the teachings contained in this disclosure, it will be apparent to persons skilled in the relevant art(s) how to make and use the invention using data processing devices, computer systems and/or computer architectures other than that shown in FIG. **5**. In particular, embodiments may operate with software, hardware, and/or operating system implementations other than those described herein.

CONCLUSION

It is to be appreciated that the Detailed Description section, and not the Summary and Abstract sections (if any), is intended to be used to interpret the claims. The Summary and Abstract sections (if any) may set forth one or more but not all exemplary embodiments of the invention as contemplated by the inventor(s), and thus, are not intended to limit the invention or the appended claims in any way.

While the invention has been described herein with reference to exemplary embodiments for exemplary fields and applications, it should be understood that the invention is not limited thereto. Other embodiments and modifications thereto are possible, and are within the scope and spirit of the invention. For example, and without limiting the generality of this paragraph, embodiments are not limited to the software, hardware, firmware, and/or entities illustrated in the figures and/or described herein. Further, embodiments (whether or not explicitly described herein) have significant utility to fields and applications beyond the examples described herein.

Embodiments have been described herein with the aid of functional building blocks illustrating the implementation of specified functions and relationships thereof. The boundaries of these functional building blocks have been arbitrarily defined herein for the convenience of the description. Alternate boundaries can be defined as long as the specified functions and relationships (or equivalents thereof) are appropriately performed. Also, alternative embodiments may perform functional blocks, steps, operations, methods, etc. using orderings different than those described herein.

References herein to "one embodiment," "an embodiment," "an example embodiment," or similar phrases, indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it would be within the knowledge of persons skilled in the relevant art(s) to incorporate such feature, structure, or characteristic into other embodiments whether or not explicitly mentioned or described herein.

The breadth and scope of the invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

What is claimed is:

1. A method for creating a hash index on-demand and reusing the hash index for queries in a database, comprising:

determining, by at least one processor, during query optimization that a first database query has a query execution plan comprising a sub-query which executes N times a correlated predicate having an operator being one of equal and not equal to a base column;

comparing, by the at least one processor, based on the correlated predicate, a cost of creating a hash index and probing the hash index N times to a cost of fully scanning the base column N times;

creating on-demand, by the at least one processor, a hash index based on the comparing; and

executing, by the at least one processor, a second database query using the hash index, wherein the executing eliminates fully scanning the base column N times.

2. The method of claim **1**, further comprising determining that the cost of creating the hash index and probing the hash index N times is less than fully scanning the base column N times, creating the hash index, and using the hash index during query execution to apply the correlated predicate.

3. The method of claim **2**, wherein the database comprises a row level versioned (RLV) store supporting row-level snapshot isolation.

4. The method of claim **3**, wherein the hash index is associated with a version of the database in the RLV store.

5. The method of claim **2**, wherein the second database query is of a same snapshot of the database, the second database query having a correlated predicate with an operator being one of equal and not equal to the base column.

6. The method of claim **1**, wherein the first database query comprises one of a correlated sub-query and a nested loop push down join query.

7. The method of claim **1**, further comprising:

determining that the cost of creating the hash index and probing the hash index N times is less than fully scanning the base column N times; and

populating the hash index, the hash index comprising a hash table associating values in a column with rows in a database table version, wherein the hash table comprises:

at least one element being a pair of a pointer to a value in the column and a row specification.

8. The method of claim **7**, wherein the row specification comprises one of a rowid, an array of rowids, and a bitmap representing rowids.

9. The method of claim **1**, further comprising:

discarding the hash index when it is determined that all database transactions using an associated table version are completed and that at least one version of the table more recent than the associated table version exists.

10. A system for creating a hash index on-demand and reusing the hash index for queries in a database, comprising:

a memory; and

at least one processor coupled to the memory and configured to:

determine during query optimization that a first database query has a query execution plan comprising a sub-query which executes N times a correlated predicate having an operator being one of equal and not equal to a base column;

determine, based on the correlated predicate, a comparison of a cost of creating a hash index and probing the hash index N times to a cost of fully scanning the base column N times;

create on-demand a hash index based on the comparison; and

execute a second database query using the hash index, wherein the execution eliminates fully scanning the base column N times.

11. The system of claim **10**, the at least one processor further configured to determine that the cost of creating the hash index and probing the hash index N times is less than fully scanning the base column N times, create the hash index, and use the hash index during query execution to apply the correlated predicate.

12. The system of claim **11**, wherein the database comprises a row level versioned (RLV) store supporting row-level snapshot isolation.

13. The system of claim **12**, wherein the hash index is associated with a version of the database in the RLV store.

14. The system of claim **11**, wherein the second database query is of a same snapshot of the database, the second database query having a correlated predicate with an operator being one of equal and not equal to the base column.

15. The system of claim **10**, wherein the first database query comprises one of a correlated sub-query and a nested loop push down join query.

16. The system of claim **10**, wherein the at least one processor is further configured to:

determine that the cost of creating the hash index and probing the hash index N times is less than fully scanning the base column N times; and

populate the hash index, the hash index comprising a hash table associating values in a column with rows in a database table version, wherein the hash table comprises:

at least one element being a pair of a pointer to a value in the column and a row specification.

17. The system of claim **16**, wherein the row specification comprises one of a rowid, an array of rowids, and a bitmap representing rowids.

18. The system of claim **10**, the at least one processor further configured to:

discard the hash index when it is determined that all database transactions using an associated table version are completed and that at least one version of the table more recent than the associated table version exists.

19. A tangible computer-readable device having instructions stored thereon that, when executed by at least one computing device, causes the at least one computing device to perform operations for creating a hash index on-demand and reusing the hash index for queries, the operations comprising:

determining during query optimization that a first database query of a database has a query execution plan comprising a sub-query which executes N times a correlated predicate having an operator being one of equal and not equal to a base column;

comparing, based on the correlated predicate, a cost of creating a hash index and probing the hash index N times to a cost of fully scanning the base column N times;

creating on-demand a hash index based on the comparing; and

executing a second database query using the hash index, wherein the executing eliminates fully scanning the base column N times.

20. The computer-readable device of claim **19**, the operations further comprising:

determining that the cost of creating the hash index and probing the hash index N times is less than fully scanning the base column N times, creating the hash index, and using the hash index during query execution to apply the correlated predicate.

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